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Chapter 8

Accuracy of Implant Casts Generated with Splinted and Non-splinted Impression Techniques for Edentulous Patients: An Optical Scanning Study

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Accuracy of implant casts generated with splinted and non-splinted impression techniques for edentulous patients: an optical scanning study

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Abstract

Background: The accuracy of implant casts generated with various impression techniques was mainly investigated *in vitro* resulting in limited clinical data.

Purpose: (1) To compare the three-dimensional (3-D) accuracy of splinted and non-splinted impression techniques to the control casts (verification jigs) that had been used for actual patient treatment; and (2) to determine the maximum level of clinically undetectable misfit. The null hypothesis was that there would be no significant difference in the accuracy of casts generated with different impression techniques.

Materials and methods: The implant casts used for the prosthetic rehabilitation of 12 edentulous jaws with CAD/CAM zirconia, implant-fixed complete dental prosthesis (IFCDP) were included in this study. Intraoral acrylic jigs were used to fabricate index casts. Splinted and non-splinted, open-tray techniques were used to generate two casts. Optical scanning acquisition of the *x*-coordinates, *y*-coordinates and *z*-coordinates of the implant positions for each individual cast was performed. The "best fit" algorithm was used with computer software to superimpose the scanning datasets. Group I ($n = 12$) included casts from the splinted impression technique vs. acrylic jig casts, and group II ($n = 12$) included casts from non-splinted technique vs. jig casts.

Results: The paired *t*-test and Wilcoxon's signed ranks test were used to compare the 3-D discrepancies within and between groups I (splinted vs. jig) and II (non-splinted vs. jig), respectively. Significant difference was found at the *x*-axis, *y*-axis and 3-D between groups I and II ($P < 0.05$), but not in the vertical *z*-axis ($P > 0.05$). Within subject, global 3-D discrepancies between groups I and II were significantly different ($P < 0.05$), corroborated by *in vivo* observations of clinical fit. Implant position in the arch affected the 3-D accuracy of casts for both anterior and posterior implants ($P < 0.05$).

Conclusion: The splinted technique generated more accurate master casts than the non-splinted technique for one-piece IFCDPs in edentulous jaws and the null hypothesis was rejected. These clinical implications demonstrate improved accuracy of splinted impression techniques compared with the non-splinted technique. For the external connection, the implant system used in this study, a 3-D misfit ranging from 59 to 72 μm, may be considered the maximum discrepancy resulting in an acceptable clinical fit with one-piece IFCDPs.

Dental implants with direct contact to the host bone cannot accommodate distortions or misfit at the implant–abutment interface (Karl et al. 2004). Although, absolute passive fit of implant-fixed complete dental prostheses (IFCDPs) is unlikely, a level of biological tolerance seems to exist (Jemt & Book 1996). However, prosthesis misfit has been related to screw loosening/fracture, implant fractures and prosthetic component strain (Eckert et al. 2000; Duyck & Naert 2002; Hjamarsson et al. 2010; Eliasson et al. 2010).

An accurate impression of the intraoral spatial orientation of the implants is necessary to generate an accurate master cast. There are several clinical and laboratory variables that affect the accuracy of an implant cast including impression and pouring techniques (Lee et al. 2008), impression material and die stone properties, machining tolerance of prosthetic components (Binon 1995; Ma et al. 1997), implant angulation and/or depth (Assuncao et al. 2010). However, the impression procedure still remains one of the most significant factors. Various implant impression techniques have been developed in an effort to generate a master cast that will ensure the most accurate clinical fit of IFCDPs. The neces-

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sity for splinting the impression copings has been advocated in various investigations (Assif et al. 1992, 1996; Vigolo et al. 2003, 2004; Assuncao et al. 2004, 2008a; Naconecy et al. 2004; Cabral & Guedes 2007; Arioli-Filho et al. 2009; Del'Acqua et al. 2010; Hariharan et al. 2010). Some studies have shown better results with the non-splinted technique (Inturregui et al. 1993; Phillips et al. 1994; Burawi et al. 1997), whereas several others have shown no difference (Humphries et al. 1990; Barrett et al. 1993; Hsu et al. 1993; Herbst et al. 2000; Kim et al. 2006; Choi et al. 2007; Assuncao et al. 2008b; Del'Acqua et al. 2008; Lee et al. 2009).

The purposes of this study were (1) to compare the three-dimensional (3-D) accuracy of splinted and non-splinted impression techniques to control casts (verification jig) that had been used for actual patient treatment; and (2) to determine the maximum level of clinically undetectable misfit. The null hypothesis was that there would be no significant difference in the accuracy of casts generated with different impression techniques.

Materials and methods

This study included the implant casts that had been used during the prosthetic rehabilitation of 12 edentulous jaws. All implants had been virtually planned and surgically placed with stereolithographic templates and all edentulous jaws had been restored with a one-piece, screw-retained CAD/CAM zirconia IFCDP at the implant level (Papaspyridakos & Lal 2010). Institutional Review Board approval for the applied surgical protocol had been obtained by the Columbia University Human Subjects Review Committee. Standardized prosthodontic and laboratory procedures were used as follows.

Impression procedures

For the splinted impression technique, acrylic stock trays (Dentsply, Milford, DE, USA) were used for all impressions in the open-tray mode. Impression copings were connected to the implants, and seating of the copings was verified radiographically. Subsequently, the copings were connected to dental floss and splinted to each other with visible light polymerized acrylic resin (Triad gel; Dentsply). The whole assembly was sectioned between all inter-implant areas and the same light polymerized acrylic resin was used to lute the copings together (Papaspyridakos & Lal 2008).

The impression material used was polyether (Impregum; 3M ESPE, St Paul, MN, USA) and additional material was injected with a disposable syringe (Monoject 412 Syringe; Salvin Dental, Charlotte, NC, USA) around the copings. For the non-splinted technique, an open-tray impression was taken for each patient following the same steps as described earlier. The only difference was that the impression copings were not splinted together.

Fabrication of casts

The laboratory pouring procedures were the same for all the impressions taken with both impression techniques. After connection of the implant analogs to the copings, low-expansion (0.09%) type IV die stone (Silky Rock; Whipmix Corp., Louisville, KY, USA) was mixed under vacuum and an initial pour of stone up to the middle of the analogs was carried out. After 30 min, the second pour of vacuum-mixed die stone was performed. This double-pouring technique minimizes the volumetric expansion of the stone and has been shown to lead to more accurate die casts (Del'Acqua et al. 2008).

Clinical procedures

A verification jig was fabricated intraorally for each patient by connecting temporary non-engaging abutments to the implants with dental floss and visible light-polymerized acrylic resin (Triad gel; Dentsply). Implant analogs were connected to the temporary abutments in the jig, and the same die stone (Silky Rock; Whipmix Corp.) was used to pour the verification jig cast. All CAD/CAM IFCDPs had been fabricated at the implant level and presented with an accurate clinical fit on the basis of clinical and radiographic criteria (Papaspyridakos & Lal 2008, Abduo et al. 2010). Before definitive insertion, all prostheses had been fitted on the splinted and non-splinted cast to indirectly assess the accuracy by two blinded examiners (Fig. 1).

Casts obtained from both impression techniques were compared with the cast derived from the verification jig (control cast), resulting in the following comparison groups:

- GROUP I: Casts generated from the splinted coping impression technique vs. casts indexed from the verification jig (control).
- GROUP II: Casts generated from the non-splinted coping impression technique vs. casts indexed from the verification jig (control).

Accuracy assessment with optical scanning

An optical scanner (IScan D101; Imetric 3D Gmbh, Courgenay, Switzerland) coupled with industrial dedicated software, which included a 3-D transformation package (ImetricS; Imetric 3D Gmbh) was used in this study to capture the 3-D orientation of the implants in each cast (Fig. 2).

The optical scanner included a light source that reaches the object with fringes of light shot by a camera (Del Corso et al. 2009). By projecting many fringes and moving them along the whole surface to be scanned, a complete scan of the object and its 3-D reconstruction was obtained.

Scan adapters (5 mm diameter and 15 mm height) were used to determine the 3-D orientation of the implant positions. The scan adapters were metallic (INOX) and cylindrical. Titanium oxide spray was used as a coating before the scanning procedure. An experienced operator blinded to the type of casts performed all scanning procedures.

First, the scan adapters were placed on cast 1 (control). The scan adapters were sprayed with titanium oxide coating and four measurements were performed without taking the model out of the scanner (Fig. 3). Then, the clean scan adapters were placed on cast 2 (splinted) and sprayed again. The same scanning procedures were performed for cast 3 (non-splinted). In the end, the scan adapters were placed back on control cast 1 and another measurement was performed. For all scans, the same scan adapters were moved from the corresponding position in set 1 to set 2 and then to set 3 in order to eliminate the effect of scan adapters. For all data sets, repeatability measurements were performed. The results showed that the accuracy was better than 5 μm in *x*-axis, *y*-axis and *z*-axis.

Fig. 1. Prosthesis seated on the cast.

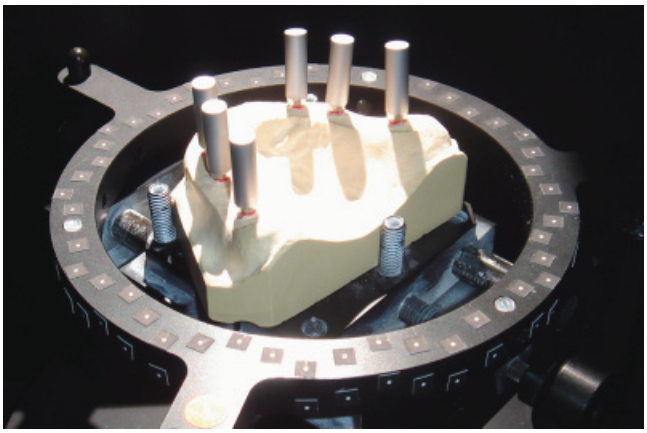

Fig. 2. Optical scanner.

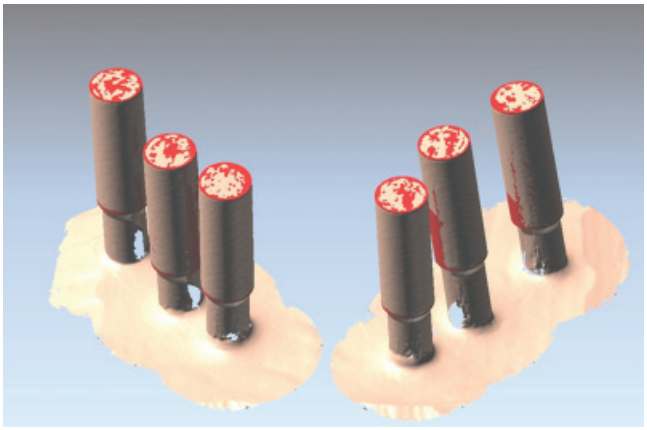

Fig. 3. Optical scanning dataset.

The optical scanning data sets from each splinted and non-splinted cast were imported in the computer with dedicated software (ImetricS) and were superimposed with the data set from the control cast, respectively (Fig. 4). The ''best fit'' algorithm was used by the computer software to superimpose the different scanning data sets (Buhler 1981). The cumulative 3-D discrepancies were calculated for each cast, using the mathematical equation $3D = \sqrt{x^2 + y^2 + z^2}$.

Comparison of all deviations in *x*-, *y*-, *z*-axis and 3-D were made between and within groups I and II, and between anterior and posterior implants in groups I and II for both maxilla and mandible, respectively. A correlation was sought between the clinical assessment of fit of the IFCDP in every implant cast and the 3-D quantitative analysis of misfit with the optical scanning in order to identify the maximum acceptable 3-D misfit. If the IFCDP fit the implant cast, the 3-D misfit detected by optical scanning was recorded as clinically acceptable. Repetitive measurements for all casts can provide a threshold of clinically acceptable misfit.

Statistical analysis

The absolute values of the 3-D discrepancies were used to analyze the overall accuracy of the two groups (absolute accuracy). The data were analyzed for normal distribution with the Kolmogorov–Smirnov test (normality test). A paired *t*-test was used for parametric data and Wilcoxon's signed ranks-test was used for non-parametric data in order to determine statistically significant discrepancies among the group I (splinted vs. control) and II (non-splinted vs. control). The level of statistical significance was set at $P \leq 0.05$.

Results

The absolute values of the discrepancies (mean, SD and range) in *x*-axis, *y*-axis, *z*-axis and the total 3-D are presented in Table 1. Mean (SD) difference for group I (splinted vs. control) was 37 (17) μm in the *x*-axis, 21 (6) mm in the *y*-axis, 9 (5) μm in the *z*-axis and 44 (17) μm in 3-D. Mean (SD) difference for group II (non-splinted vs. control) was 53 (22) μm in the *x*-axis, 46 (28) μm in the *y*-axis, 37 (64) μm in the *z*-axis and 89 (60) μm in 3-D. The Kolmogorov–Smirnov test showed that the data were normally distributed ($P > 0.05$).

The paired *t*-test showed significant differences in the *x*-axis, *y*-axis and 3-D ($P < 0.05$) within groups I and II. No statistically significant difference was found ($P > 0.05$) in the vertical axis (*z*-axis). Wilcoxon's signed ranks test showed similar significant differences in the *x*-axis, *y*-axis and 3-D between groups I and II ($P < 0.05$). No statistical significance was found ($P > 0.05$) in the vertical axis (Table 1).

Within subject, global 3-D discrepancies between groups I and II were statistically different ($P < 0.05$) such that the splinted technique produced more accurate casts than the non-splinted technique. The outcomes demonstrated by optical scanning were corroborated by observations from the clinical fit (Table 2). Before delivery, the zirconia prosthesis had been fitted on the splinted and non-splinted casts. The clinical fit was acceptable in 11 out of the 12 splinted casts, and in six out of the 12 non-splinted casts, respectively. The clinical observations and their correlation with the optical scanning measurements can be seen in Table 2. When the one-piece IFCDP was seated in an implant cast, the greatest 3-D deviation that resulted in a clinical fit was 59 μm. Conversely, the smallest 3-D deviation that resulted in a clinical misfit was of 72 μm. Hence, for the external connection implant system used in this study, a maximum tolerable misfit between 59 and 72 μm was found.

The effect of the implant position in the dental arch and the 3-D positional accuracy is shown in Table 3. The implant position in the dental arch affected the accuracy of the casts for both anterior and posterior implants ($P < 0.05$). Specifically, both anterior and posterior implants of group I (splinted) presented with less 3-D deviations than the implants of group II (non-splinted).

Discussion

Passive fit of implant prosthesis depends on the accuracy of the implant cast, which is directly dependent on the accuracy of the impression technique. Several studies have indirectly assessed the accuracy of implant impressions by evaluating the fit and/or distortion of fabricated frameworks on the resultant casts with strain gauges and compared the fit and/or distortion of the frameworks on the reference master cast (Inturregui et al. 1993; Assif et al. 1996; Naconecy et al. 2004; Choi et al. 2007). Other studies have evaluated the accuracy of the implant impressions by measuring inter-implant distances of the working casts in relation to a reference con-

trol cast (Humphries et al. 1990; Hsu et al. 1993; Herbst et al. 2000; Wee 2000; Assuncao et al. 2004, 2008a, 2008b; Vigolo et al. 2004). Computerized coordinate measuring machine, photogrammetry, optical microscope, laser videography and recently, optical scanning are some of the techniques that have been used in the assessment of inter-implant 3-D deviations (Jemt et al. 1999; Wee 2000; Del Corso et al. 2009; Eliasson et al. 2010). For this study, an optical scanner (IScan D101) with dedicated software was used in the accuracy measurements. The repeatability of the scanner was confirmed by unscrewing the scan adapters after every scan, re-screwing them back and re-scanning each cast and it showed accuracy better than 5 μm. The analysis of the results was performed using industrial software (ImetricS) with a 3-D spatial transformation package.

The present study showed that the accuracy of casts produced with the splinted technique was significantly superior to casts produced with the non-splinted technique. These findings suggest that splinting the copings may result in more accurate casts for one-piece IFCDPs in edentulous jaws. Sectioning and soldering gold frameworks have been suggested as an alternate modality to compensate for impression inaccuracies. However, it is associated with additional treatment time and cost (Carr & Master 1996). The advent of CAD/CAM technology improved the framework fabrication procedures and increased the precision of fit for one-piece IFCDPs (Ortorp et al. 2003; Al-Fadda et al. 2007; Papaspyridakos & Lal 2008). Other prosthetic designs such as segmented prostheses and multiple strategically positioned implants have also been proposed for complete arch-fixed rehabilitations. A splinted impression coping technique may be less significant when a segmented rehabilitation for edentulous or partially edentulous patients is contemplated (Gallucci et al. 2005). In addition, the implant position in the dental arch had an effect in the 3-D accuracy of the casts of groups I and II for both anterior and posterior implants ($P<0.05$). The curvature of the arch and the greater antero-posterior spread may explain this observation.

Previous *in vitro* studies comparing splinted with non-splinted impression techniques have reported diverse results. The necessity for splinting the impression copings has been advocated in various investigations. Other studies showed better results with the non-splinted technique, whereas several others have shown no difference. Pertaining to edentulous situations with four or more implants, the preponderance of *in vitro* studies advocated the splinted impression technique (Lee et al. 2008). It must be highlighted that most studies published after 2003 advocate the splinted technique. Thus, the findings of the present study are in accordance with the majority of published *in vitro* studies regarding completely edentulous situations.

The diverse results from some previous *in vitro* studies may be partially explained by the machining tolerance of components, by the differences in methods for accuracy measurements and by improvements in dental materials. Paired prosthetic components may be rotationally displaced during connection to their respective parts (Kim et al. 2006). This displacement cannot be controlled by the clinician and lies within the range of the inherent machining tolerance (Binon 1995, Cheshire & Hobkirk 1996; Ma et al. 1997). Hence, errors occur during the connection of impression copings to the implants intraorally and to the implant analogs in the laboratory, respectively. For instance, Inturregui and colleagues performed a comparative *in vitro* study with first-generation prosthetic components of the Branemark System. Ma and colleagues showed that the machining tolerance of the first-generation components was larger than the currently used components and ranged from 33 to 100 μm. The machining tolerance differs between different implant systems and is an unknown variable in accuracy measurements. Moreover, the use of new splinting materials like

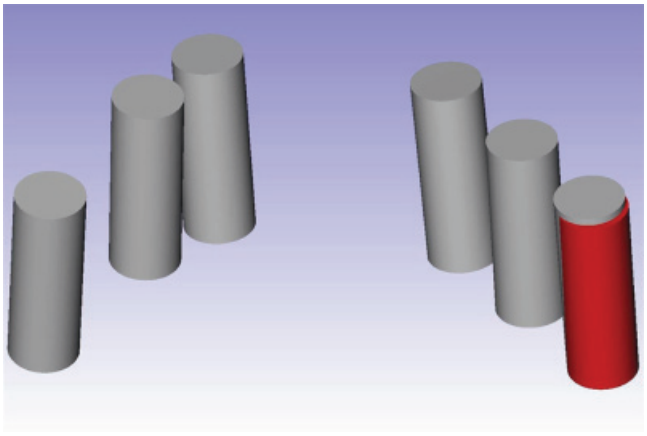

Fig. 4. Superimposed scanning datasets.

Table 1. **Mean values, minimum, maximum and standard deviation (in μm) for Groups I and II**

Axis	Group I (splinted vs. jig)				Group II (non-splinted vs. jig)				*P*-value†	*P*-value‡
	Mean	SD	Min	Max	Mean	SD	Min	Max		
x	37	17	24	89	53	22	22	99	0.009*	0.015*
y	21	6	14	29	46	28	23	125	0.014*	0.004*
z	9	5	4	16	37	64	5	196	0.160	0.347
3-D	44	17	30	93	89	60	36	241	0.025*	0.003*

*Statistical significance $P \leq 0.05$.
†Paired *t*-test.
‡Wilcoxon's signed ranks test for dependent variables.
SD, standard deviation.

Table 2. **Within-subject comparison of global three-dimensional (3-D) deviations (in μm)**

Subject	01	02	03	04	05	06	07	08	09	10	11	12	Mean global 3-D deviation
Group I Global[1] 3-D deviation	37	42	30	51	42	40	35	33	51	93	38	39	44
Group II Global[2] 3-D deviation	36	85	72	57	50	241	44	59	170	104	92	56	89
Difference between Global[1] and Global[2]	1	43	42	6	8	201	9	26	119	11	54	17	55
Clinical fit	Both	Splint	Splint	Both	Both	Splint	Both	Both	Splint	None	Splint	Both	*P*-value†: 0.025*

†Paired *t*-test.
*Statistical significance $P \leq 0.05$.

Table 3. **Effect of the implant position in the three-dimensional (3-D) positional accuracy (in μm)**

	Implants (*n*)	Mean (SD)								*P*-value†
		Group I (splinted vs. jig)				Group II (non-splinted vs. jig)				
		x	*y*	*z*	3-D	*x*	*y*	*z*	3-D	
Maxilla										
Anteriors	13	52	22	12	51 (28)	66	46	87	96 (72)	0.016*
Posteriors	13	55	24	11	53 (31)	65	45	55	84 (50)	0.033*
Mandible										
Anteriors	20	29	20	11	38 (15)	51	40	9	60 (21)	0.006*
Posteriors	26	36	22	8	33 (18)	54	66	94	71 (108)	0.05*

†Wilcoxon's signed ranks test for dependent variables.
*Statistical significance $P \leq 0.05$.
SD, standard deviation.

composite resin or light polymerizing acrylic resin resulted in better results (Del'Acqua et al. 2010).

This study did not consider the effect of angulation or depth of implants on the accuracy of implant procedures. However, the fact that all 72 implants had been placed with prosthodontically driven, CT-generated templates using interactive planning software minimized the differences. The laboratory procedures of pouring the casts were also standardized and carried out by one clinician. All prostheses had been fabricated with rapid prototyping and CAD/CAM technology and presented accurate clinical fit on the basis of stringent clinical and radiographic criteria (Abduo et al. 2010).

Clinically derived outcomes of the effect of splinted vs. non-splinted implant impression techniques reported for the first time in this investigation, appear to have significant weight when compared with *in vitro* studies. However, further clinical studies with a larger sample are needed to corroborate the findings of the present study. Comparisons between implant impressions with copings that can be digitally scanned intraorally and superimposed may provide the foundation for future research.

Conclusion

The hypothesis that there would be no clinical difference in the accuracy of definitive implant casts produced by the tested implant impression techniques was rejected. Under the limitations of the present study, the following conclusions can be drawn:

1. The splinted impression technique produced more accurate casts compared with the non-splinted technique ($P<0.05$). Statistically significant difference ($P<0.05$) was found at the *x*-axis, *y*-axis and 3-D between groups I (splinted vs. control) and II (non-splinted vs. control). No statistically significant difference was found ($P>0.05$) in the *z*-axis.
2. Within subject, global 3-D discrepancies between group I and II were statistically different ($P<0.05$). These findings were confirmed by *in vivo* observations of clinical fit (true positive).
3. The clinical implications of this study indicate the supremacy of the splinted impression technique over the non-splinted technique in generating more accurate casts for one-piece IFCDPs in edentulous patients.
4. The implant position in the dental arch had an effect in the accuracy of the casts of groups I and II for both anterior and posterior implants ($P<0.05$).
5. For the external connection implant system used in this study, a 3-D misfit ranging from 59 to 72 μm may be considered the maximum discrepancy resulting in an acceptable clinical fit with one-piece IFCDPs.

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